Pickering (E. C.) 6

REPORT ON THE

PHYSICAL LABORATORY

OF THE

MASS. INSTITUTE OF TECHNOLOGY.

To Professor J. D. Runkle, *President pro tempore of the Institute:* —

As the method of giving instruction in Physics by means of a laboratory is now attracting a good deal of attention both in this country and in Europe, it seems desirable to make known the success which has attended a laboratory of this kind lately established at the Institute. Its history is as follows: —

1864. President Rogers[1] proposed a laboratory in which "the student may be exercised in a variety of mechanical and physical processes and experiments."

1868, Oct. A room was opened to advanced students where they carried on physical investigations, as is done by many physicists, with their special students.

1869, April. The plan described below was presented by the writer and adopted by the Government of the Institute.[2]

1869, Oct. This plan was carried out, and the laboratory opened to the regular students of the Institute.

[1] Scope and Plan of the School of Industrial Science of the Mass. Institute of Technology, p. 24.

[2] Supplement to the Fourth Annual Catalogue. Plan of the Physical Laboratory. 8vo. Pamph., pp. 16.

Its first object is to enable the regular students of the Institute, after attending a course of lectures on Physics, to verify its laws and measure its constants, also to learn to use the more important pieces of apparatus. Secondly, to instruct special students in the use of particular instruments, or branches of physics, as the spectroscope, microscope, photometry, electrical measurements, etc. Thirdly, to prepare teachers of this science. And fourthly, to afford facilities to physicists to carry on investigations at the Institute.

In carrying out the first part of this plan the following difficulties presented themselves. How could experiments be performed by twenty or thirty students at a time, without duplicating apparatus to an extent which would involve a very great outlay, and how could each obtain sufficient attention from the instructor, to enable him to work with advantage? Moreover, since physical apparatus is often delicate and expensive, would not the injury and breakage, both in moving and using it, be so great as to render the current expenses of the laboratory very large? It will be seen that these difficulties were obviated by the adoption of the following plan. Two adjacent rooms were fitted up with tables, and supplied with water and gas as in a chemical laboratory. On each table is placed the apparatus necessary for a single experiment together with a complete written description. Between the two rooms is an indicator, or frame with cards containing the names of the experiments, and opposite each, a second card with the name of a student. Each member of the class on entering the rooms notices where his card is placed, goes to the proper table, reads the description, and sometimes is able to perform the experiment without any assistance from the instructor. The time of the latter is therefore sufficiently unoccupied to enable him to go from desk to desk, and watch carefully that no serious errors are committed. When an experiment is completed the card of the student is placed opposite some unoccupied table and he goes on as before. Since the number of experiments is

greater than that of students, several places are always vacant, and delays are avoided. New experiments are added at intervals to replace those which have been performed.

By this plan there is no need of duplicating apparatus, and since it always remains in the same place, the danger of breakage is very small; in fact, during the past year the loss in this way has amounted to almost nothing. It is, moreover, always ready for use, and so much time is saved in this way, that each student accomplishes a large amount of work. So much more, in fact, than was anticipated, as to cause during the past year some difficulty in supplying enough new experiments. The nature of the work done is best shown by the following examples.

Deflection of Beams. I. A steel bar rests on two knife-edges and to it is attached a scale-pan on which are placed successively, 100, 200, 300 to 1900 grammes, and the flexure measured by a micrometer screw, reading to $\frac{1}{2000}$ of an inch. The point of contact is determined with the utmost precision by connecting micrometer and bar with a galvanic battery and galvanometer, in such a way that the current only passes when the two former are in contact. The screw is turned until the needle moves, and the reading is then taken. The results are represented by a curve, in which horizontal distances correspond to weights, and vertical to deflections. This should give a straight line, and in many cases the difference is so small as to be scarcely perceptible to the eye. The experiment is then repeated, keeping the weight constant in amount, but altering its position. By moving knife-edges, micrometer or weight, and changing the magnitude of the latter, this experiment may be infinitely varied.

Deflection of Beams. II. A mirror is attached to the end of a beam, and the image of a scale is viewed in a telescope placed opposite it; a method of very general application for measuring small changes of position.

Hook's Joint. A model of Oldham's modification of this form of universal joint, has a graduated circle attached to each axle. One is made to vary uniformly 5° at a time, and the difference in position of the two wheels is recorded. The result is represented by a curve, in which horizontal distances represent the position of the first wheel, and vertical the difference in the two readings. The values given by the formula tang a = cos A tang b, are then computed, and the theoretical curve constructed on the same sheet of paper.

Law of Lenses. The image of a gas flame is projected on a screen by means of a lens, and the latter is moved half a foot at a time.

The image is focussed by moving the screen, and the positions of the latter are compared with the theory by means of two curves, as in the preceding experiment.

Spherometer. The radius of curvature of each surface of two lenses is measured, and their foci computed.

Hydrometers. The specific gravity of several liquids is measured by these instruments, also of a solid by Nicholson's hydrometer.

Gauge Flask. The specific gravity of a liquid and solid is measured in this way also.

Mohr's Balance. The specific gravity of similar substances measured a third time by the hydrostatic balance.

Specific Heat. The specific heat of a stone measured by the calorimeter, first testing the method by water.

Opthalmoscope. A model of the eye intended for use with this instrument has been procured, together with representations of the principal diseases of the retina, and means of imitating near or far-sightedness and astigmatism. The student views the retina under these various conditions, using both the direct and the inverted image, and finally a diseased retina is inserted, and he is required to draw it as seen with the opthalmoscope.

Spectroscope. The principal lines of the solar spectrum, also those of the spectra of soda, lithium, baryta, strontia and lime, are measured and drawn. Three mixtures of these substances are then given to the pupil, which he is required to analyze.

Microscope. I. With this instrument the student views various objects, one being selected to show the effect of a diaphragm, another for oblique illumination, a third for reflected light, etc.

Microscope. II. With a more complex microscope he makes drawings with a camera lucida, uses a lieberkuhn, and measures various distances with stage and eye-piece micrometers.

Polariscope. A simple form of polariscope with a piece of common glass for a polarizer is used with plates of selenite, crystals and compressed and unannealed glass.

Cross Hairs. This experiment consists in the insertion of cross hairs in the eye-piece of a common telescope or microscope. It is done by unravelling a common silk thread, and stretching two filaments at right angles to each other on a circle of card-board, which is then fastened to the diaphragm of the eye-piece. Considerable tension is needed to render them straight, and as they are nearly as fine as a spider's web the student acquires a good deal of delicacy of touch in handling them.

Cathetometer. This instrument is placed opposite a bent tube in which a short column of mercury balances a long column of water. Their lengths are measured, and from this the specific gravity of the mercury is deduced. A barometer tube is next filled and its height measured, deducing the level of the mercury by the usual method with a pointed steel rod. The result is finally compared with a standard barometer.

The above are some of the most successful experiments we have used, of which the whole number exceeds forty, and will probably be nearly doubled during the coming year. In selecting experiments, care is taken to introduce some which shall illustrate general methods of research, such as the micrometer screw, verniers, interpolation, computation of probable errors, etc. The graphical method is very largely used, both from its value in studying laws, and from the facility it affords for determining the accuracy of the results. As stated above, when practicable, two curves are drawn on the same sheet; one obtained by experiment, the other by computation. The student has thus the most convincing proof of the correctness of his theory.

The scale on which this laboratory has been tried, is such as to render its success no longer a matter of conjecture. In October last, the Third Year's Class, numbering twenty-three students, were admitted into it, and have since then had thirty-six exercises of one hour each. In March, the Second Year's Class, of twenty-four students, entered it, and have had twelve exercises. The total number, including special students, amounts to nearly sixty. The Third Class performed about four hundred experiments, the Second Class two hundred; the greater relative number of the latter being mainly due to the fact that the apparatus was in more perfect working order after being used for some months. Most of the experiments described above occupy but one hour, although such as the microscope and spectroscope require a longer time. Accordingly, an average student could perform all the experiments of the above series in less than thirty exercises of one hour each, and would thus acquire a far more practical knowledge of physics than by devoting the same time to lectures. Since the regular course of manipulations at the Institute is more than double this number, it is believed that each student will acquire as extended a knowledge of practical physics as is needed for everyday life.

The degree of accuracy attained in these experiments is

much greater than was anticipated, and led to the belief that investigations could be carried on, in which most of the experimental portion should be done by students. Such work would be of the utmost value to them, since, while learning to use the apparatus, they would be initiated into the methods of conducting researches, while the results being obtained by several independent observers, would be free from personal errors. To test this plan, experiments were made to determine the degree of accuracy attainable with the hook gauge, the calibration of gas meters, the perfection of compensation of the so-called "cycloid" of gas holders, and various other questions. The results will be published elsewhere, and are so encouraging that this method will be greatly extended during the coming year.

Students in the higher classes who wish to pursue Physics further, after finishing the above course, perform more difficult experiments, and carry on original investigations. As an example of the work thus accomplished, see an article by Mr. Chas. R. Cross, On the Focal Length of Microscope Objectives, in the Journal of the Franklin Institute, for June, 1870.

When a student wishes to pursue a special branch of physics, or to study a single instrument, the course is arranged to suit the requirements of each case. For example, a student, wishing to learn to use the spectroscope, would first perform the experiments of the general course bearing on this subject, such as measurement of the angles of prisms, of the power of telescopes, insertion of cross-hairs, determination of the index of refraction of different rays, and the wave lengths of the more prominent lines of the spectrum. He would also use the spectroscope, as described above, only with a greater variety of substances. After attaining some proficiency with this instrument, in which measurements are made with a photographed scale, a second spectroscope with graduated circle is given him, and with it he measures as before, the principal lines of the solar spectrum. He then constructs a curve, in which vertical distances represent scale-readings and horizontal wave-

lengths, and thus has a means of reducing all his measurements to the normal spectrum. This method is then applied to electric spectra, obtained by a Ruhmkorff coil. The lines of gases are obtained by Gessler tubes, those of metals by using them as terminals, also by drawing the spark from the surface of solutions of their salts. These measurements are reduced to wave lengths by the curve, and platted as before. In this experiment he learns to prepare a battery, and to use the induction coil. Next, he uses the large spectroscope belonging to the Institute (which produces a dispersion equal to eleven prisms of 60°), and with this he compares parts of the solar spectrum with Angstrom's chart, new lines being measured by the spider line micrometer, and interpolated from those on the map. He also reverses spectra and projects images on the slit with this instrument. The projection of the solar and metallic spectra on a screen and the spectrum-microscope will be added hereafter, and eventually the means of observing astronomical spectra, especially those of the solar protuberances. This example is selected since it has been performed substantially, as here described, by a student in spectroscopy.

Although the large number of colleges springing up all over the country has caused quite a demand for physicists, yet heretofore there has been no place where a young man could be specially educated for this profession, and consequently instructors have, in many cases, been selected from those who previously have devoted but little attention to this subject. To teach physics properly it is necessary that the instructor, besides possessing a knowledge of its phenomena and laws, which can be obtained from text-books and lectures, should be a skillful experimenter; and he should be able to construct, or at least superintend the construction of apparatus, since most institutions are unable to afford to purchase large quantities of that already made. If, as is usually the case, the instruction is given by lectures, he must be able to speak fluently, and to perform difficult experiments in the presence of an audience.

This course, therefore, in addition to the lectures and manipulations described above, will offer an opportunity to the student to perform all the more common lecture room experiments, and especially the projection of photographs and other objects on the screen, using the electric and other lights. After each lecture given to the regular students of the Institute, he will be expected to repeat all the experiments there tried. Special instruction will be given in designing apparatus and preparing estimates of its cost. It so often happens that a physicist is dependent on his own resources for most of his apparatus that students will be urged to make various instruments themselves, and will be shown how gas and steam fittings may be used, and how much may be accomplished by the aid of the carpenter and tinman.

To give him ease in addressing an audience, exercises will be held in which each student in turn will present essays on various physical subjects illustrated by experiments, care being taken to select such as will be of value to all members of the class.

The fourth object of the laboratory is to supply a place where investigations of a high order can be carried on. A physicist can here have water, gas, steam, and apparatus of all kinds, which could elsewhere be obtained only at great expense. The large size of one of our rooms (nearly an hundred feet in length) enables many experiments to be tried on a much larger scale than is usually practicable, while assistants can be obtained from among the more advanced pupils of the laboratory with mutual advantage to both parties.

In conclusion, it seems scarcely necessary to point out the advantages of the laboratory system of teaching physics, since the tendency of all technical education is now in this direction. In Chemistry, especially, this method has proved so successful as to have almost superseded instruction by lectures, at least in the larger schools and colleges.

Respectfully submitted,

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